Methods for Optimal Work Instruction Delivery: Pictograms v Images

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C. McAlinden[1], J. Butterfield[1], J. Cole[1], R. Burke[2]

1. School of Mechanical & Aerospace Engineering, Queen's University Belfast

2. Bombardier Aerospace, Belfast

ABSTRACT

This paper focuses on quantifying the benefits of pictogram based instructions relative to static images for work instruction delivery. The assembly of a stiffened aircraft panel has been used as an exemplar for the work which seeks to address the challenge of identifying an instructional mode that can be location or language neutral while at the same time optimising assembly build times and maintaining build quality. Key performance parameters measured using a series of panel build experiments conducted by two separate groups were: overall build time, the number of subject references to instructional media, the number of build errors and the time taken to correct any mistakes. Overall build time for five builds for a group using pictogram instructions was about 20% lower than for the group using image based instructions. Also, the pictogram group made fewer errors. Although previous work identified that animated instructions result in optimal build times, the language neutrality of pictograms as well as the fact that they can be used without visualisation hardware mean that, on balance, they have broader applicability in terms of transferring assembly knowledge to the manufacturing environment.

KEYWORDS: (work instructions, pictograms, learning)

1.0 Introduction

The evolution of more international supply chains has had a significant impact on how companies operate [1]. Businesses moving or creating work overseas can bring obvious advantages such as lower labour costs but with this benefit comes new challenges such as cultural and language barriers, longer learning curves and the possibility of lower quality products. A learning curve reflects the fact that the time required to accomplish any repetitive operation decreases as the operation is repeated and that the magnitude of this decrease will be less with each successive operation. To address these issues, manufacturers have to overcome challenges in the communication of engineering data and the implementation of efficient working practices. Information and knowledge generated within the design domain must be transferred effectively to the manufacturing disciplines not only within their own company but across organisations and beyond international borders.

In the aerospace industry, manufacturers are interested in not only improving their build time and reducing costs, but ensuring that final products meet stringent quality standards, due to the safety implications of build errors or sub-standard work. This consideration is becoming more relevant as aerospace production becomes more global.

Various studies have shown the impact that media type can have on knowledge acquisition and transfer [2, 3, 4]. Research has been carried out investigating how media types such as animation, static imagery and text based instructions can influence the build times for an engineering assembly. Although animations have been proven to be optimal in terms of work instruction delivery [5], not every organisation, production unit or work cell will have access to the computational hardware required to deliver animated work instructions direct to the operator.
This work seeks to compare pictogram based work instructions with static images as a means of providing work instructions for an assembly based task. The media types used in this instance have been chosen to match what would typically be available as a lowest common denominator for instruction delivery in a typical factory environment. The main objectives of the work were to use two groups of five individuals to complete five builds each of an apron uplock assembly (stiffened panel from a regional jet fuselage) using either pictogram or image based instructions. Primary build parameters were recorded as a means of comparing the instructional media. These included overall build time, number of references to instructions, number of build errors and the time for any corrective work. The results of the experiment were examined using statistical analysis to identify any trends and confirm the validity of the main outcomes.

2.0 Method

The pictogram and image based instructions were both created using a CAD model of the apron and uplock panel (see Figures 1 and 2) and still images from this model were used as the core information for both sets of instructions. Bombardier Aerospace, Belfast, authored the pictogram instructions using a spreadsheet environment.

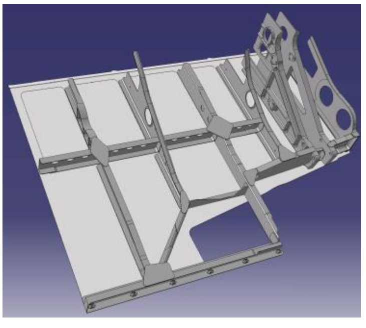

Figure 1: Apron and uplock panel.

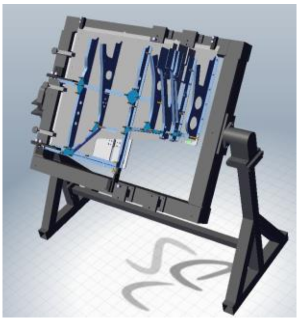

Figure 2: Panel shown in assembly fixture.

Figure 3 shows an example of a pictogram instruction where the static image is enhanced with 'lift and place' and 'fasten' pictograms (Figure 3, lower left) as well as data related to part numbers and an image of the part in its assembled position. The purely image based instruction is simply a graphic illustration of the part complete with its location and part number (see Figure 4). Both the pictograms and image instructions were viewed using hardcopy versions on printed paper with an individual step on each page.

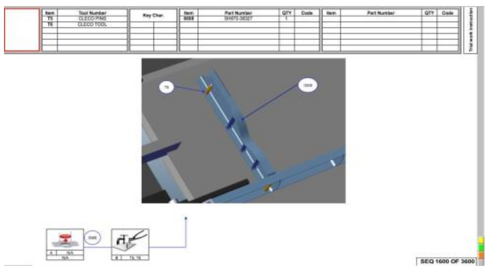

Figure 3: Pictogram instruction.

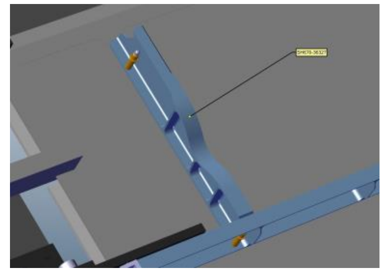

Figure 4: Image based instruction.

Preliminary builds were carried out using the instructions to validate that they were clear and contained no errors. The parts were laid out in order of use on a workbench prior to their assembly. Cleco pins were used to secure each part to the panel, using the cleco pliers (Figure 5) and a jig bar was used to tighten the fasteners on the jig clamps (Figure 6).

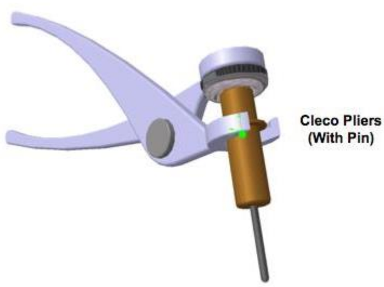

Figure 5: Cleco pin with pliers.

Figure 6: Jig bar.

Before each participant commenced the assembly process they were given fifteen minutes to familiarise themselves with the tools, fixture and instructions. This was done for all participants to ensure that all learning was based purely on the panel build and not on the instructions themselves.

The ten participants were university students studying engineering, material science or law but they were all considered to be novices since none had prior experience in aerospace assemblies.

3.0 Results

3.1 Build Times

Figures 7 and 8 show that all participants generally improved their times on each successive build in line with conventional learning curve theory (see section 1). There were, however, three occasions when the time taken to build the assembly was greater than the previous time. This occurred once for participants A and D in the image group (see Figure 7) and once for participant F in the pictogram group (see Figure 8). The correction of build errors was the cause of these increases in all cases. The difference between the mean build time at build 1 for the two groups was 5 minutes, with the image group taking longer. The average fluctuated to 10.9 minutes for build 2, 3 minutes for build 3, 7.2 minutes at build 4 and ended at 3.3 minutes at build 5 (Figure 9). At no stage did the image group complete their builds faster than the pictogram group, on average.

However, t-tests for the difference in the mean build time for the initial two builds and build 5 were not significant. It is relevant to note that within each group there was a wide variety of build times for the initial builds. For build 1, the standard deviations in build time for the pictogram and image groups were 24.5 minutes and 11.8 minutes respectively. These values dropped noticeably to 4.9 minutes and 1.7 minutes for build 5 showing that, while there was a variety of abilities initially, all members in each group were converging towards a consistent build time by build 5.

By calculating the area under the learning curves shown in Figure 9 (to determine total build time over five builds) it was found that the time taken to complete the pictogram builds was about 20% less than that for the image group.

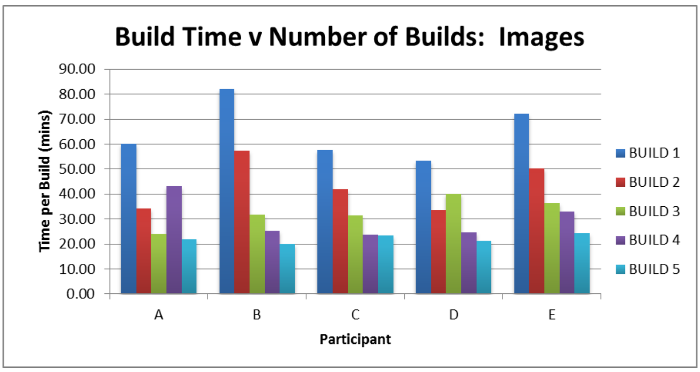

Figure 7: Variation of build time with build number, image based instructions.

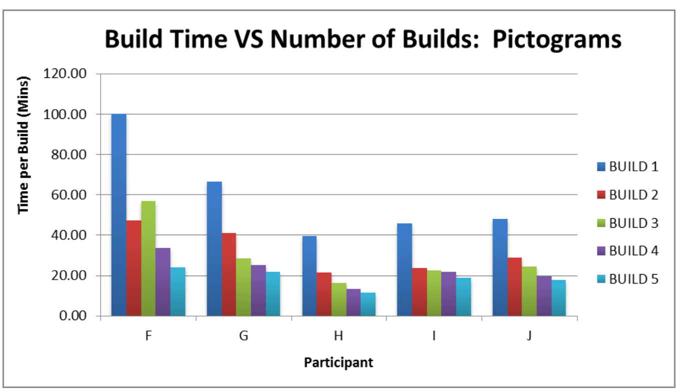

Figure 8: Variation of build time with build number, pictogram based instructions.

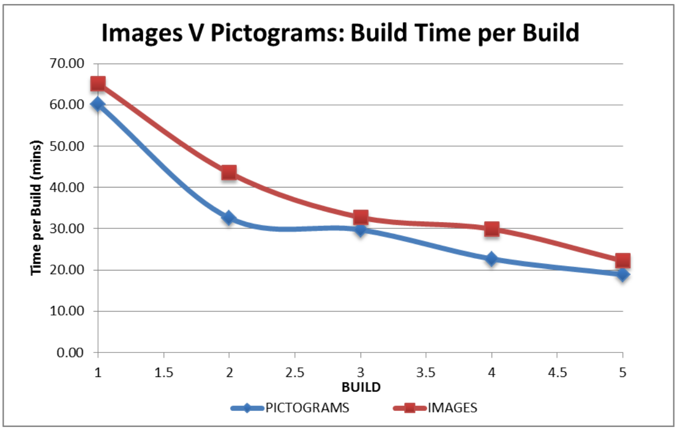

Figure 9: Average build time per build: images v pictograms.

3.2 Media References

The number of times that each participant referred to their instructions was recorded for each of their five builds. Figures 10 and 11 show how the number of media references decreased from build 1 to build 5. Again this is in line with learning curve theory although patterns varied between individuals. The number of references was largely similar for both media types, excluding the first build when the pictogram group made, on average, eleven more references than the image group. At build five, the average number of media references was almost the same for the two groups. Figure 12 shows a comparison of the number of media references per build for the two media types. t-tests show that, for the first two builds and build 5, there was no significant difference in the mean number of media references for the two media types.

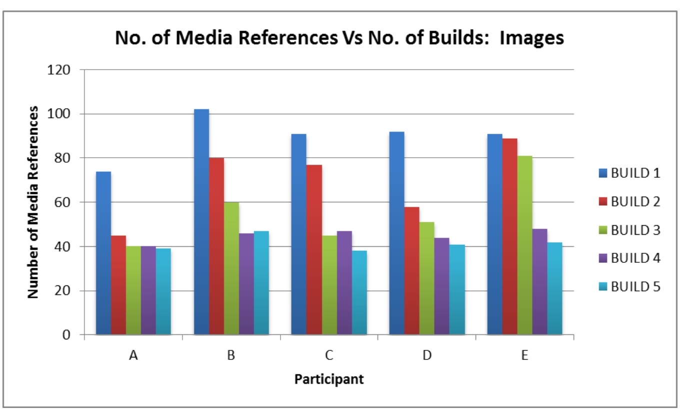

Figure 10: Variation of number of media references with build number, image based instructions.

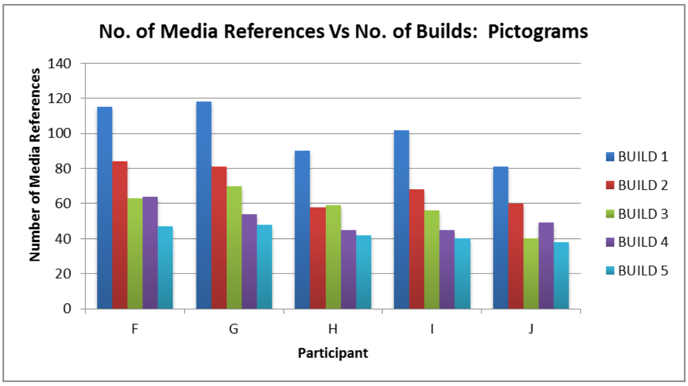

Figure 11: Variation of number of media references with build number, pictogram based instructions.

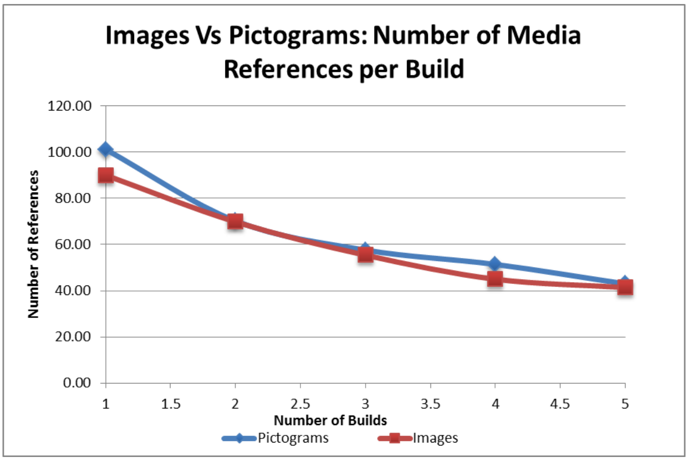

Figure 12: Average number of media references per build: images v pictograms.

3.3 Build Errors

Figure 13 shows the total number of errors for each build for the pictogram and image groups. The group which used pictograms made fewer errors at each successive build. However, taking the inter-participant variation into account, a statistically significant difference in the mean number of errors (for builds 1, 2 and 4) for the two groups was not established.

The total time to correct errors for each group is displayed in Figure 14. While the image group made almost twice as many errors than the pictogram group at build 1, they required over three times longer to correct their errors. The time required for correcting errors became negligible for the pictogram group by build 5 but the image group still spent a few minutes correcting errors.

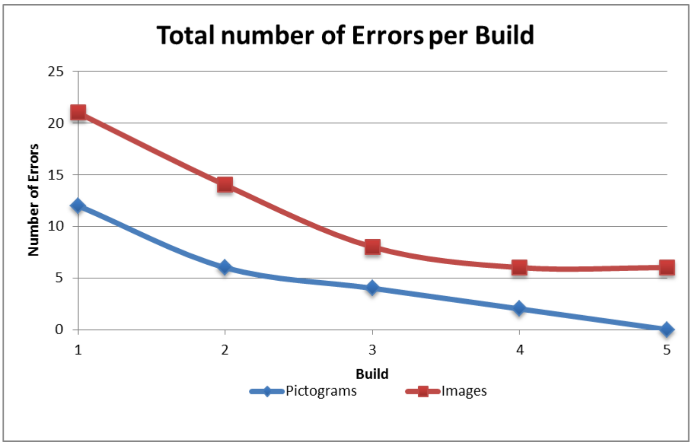

Figure 13: Comparison of total number of errors per build.

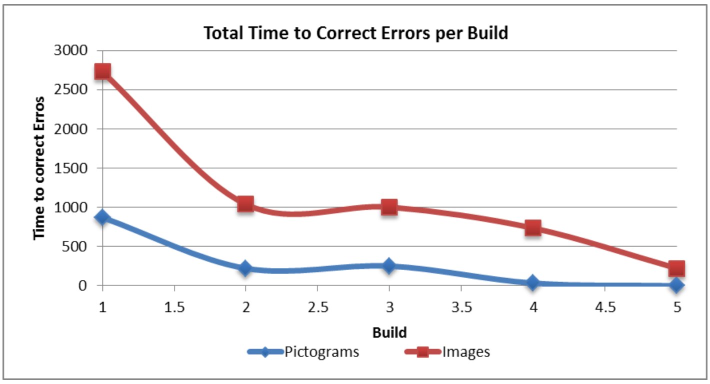

Figure 14: Comparison of total time to correct errors.

3.4 Experimental Observations

3.1. In the initial builds participants lifted either one cleco pin at a time or they used a handful and attached them as needed for each step. As the builds progressed participants lifted the correct number of cleco pins required for each step and used them before moving to the next step. This saved time turning to either lift more cleco pins or return unused pins.

3.2. All participants realised that their parts were arranged in order of use and the majority (five in pictogram group and four in image group) moved all parts closer to the edge of the bench for ease of access. The parts were initially spaced across the bench to allow for ease of viewing.

3.3. The cleco pins were placed in a container on the table behind the participants. This was mainly due to space restrictions in the lab. This meant that, during the initial builds, participants had to turn around to lift cleco pins when needed. Eight out of the ten participants chose to place the container on a flat surface on the jig to improve ease of access. This resulted in a more efficient work environment.

3.4. The time that each person spent looking at each reference reduced as the builds progressed. In the initial builds the participant would look at each instruction for 20-60 seconds to fully grasp what was being depicted. By the last build every participant had a one or two second glance at the instructions to verify the next step.

4.0 Discussion

Build Time: When comparing the pictogram group with the image group, no statistically significant difference in mean build time was observed. Further investigation with carefully chosen, larger samples should be performed. However, the consistently quicker builds (on average) for the pictogram group and the overall 20% lower build time for the five builds are interesting. This may be related to the fact that the cognitive effort required to draw the key information from pictogram instructions is less than that required for the image only instructions. Cognitive load theory [6, 7] states there is a capacity to a person's working memory that makes it a limiting factor when following instructions with low detail. The participant needs to exert cognitive effort to fill in any gaps in information. The image only instructions provide relatively low levels of instructional detail and require the participant to create a mental model of each step in order to gather the full detail of the operation. With the coded images in the pictograms, the supplementary information lowers the cognitive load on the participant allowing them to dissect each instruction with a lower effort level. This is due to the fact that the coded symbols in the pictograms helped fill any gaps.

Media References: There was no discernible difference in the number of media references between the two instruction types. However the pictogram group appeared to spend less time looking at each instruction with each reference as the builds progressed. This factor of comprehension and the speed that the participants gain information from different media types could be one of the contributing factors in the difference in build times.
Participants were instructed at the beginning of the experiment to ensure that they referred to the instructions for each step and not to rely on memory. The preceding study [5] was completed without the participants being asked to do this. This resulted in media reference numbers that were lower than the number of steps required to complete the task – one build had zero media references. The decision was made to advise participants to refer to instructions at each step, as this may be required in an industrial assembly setting. In the aerospace industry, companies need to comply with the AS9100 standard of quality management. As a stipulation of this, they need to ensure that the workforce build to specification using the approved drawings for any particular assembly. As aerospace systems are typically large and complex with many manufacturers building multiple variants of products, memory reliant assembly poses a huge risk of increasing operator error. In particular, in the cases where mixed model and multi-model flow regimes are employed, the highest risk is presented as operators can be working on different variants throughout the day – relying on memory in these situations may lead to an increased number of errors.

Build Errors: It was important for the purposes of this work that the effect that the different media types had on build quality was monitored. The time taken for the pictogram group to correct errors was about 80% less than that for the image group. Thus, in terms of the time taken to achieve appropriate build quality, pictograms delivered a higher standard of product for every build. The pictogram group made fewer errors over the builds and by build 5 the total number of errors made by the group was zero. Again, some caution is required given that a statistically significant difference in the mean number of errors was not observed. The difference in this variable may also be related to cognitive load theory [7]. The participants use the instructions to create a mental model of each step. If the information regarding the full model can be comprehended from the instructions, the participant models their own version of the instructions which may not be correct. With instructions that are open to interpretation, errors are more likely to happen. When using pictograms, there is less opportunity for the participants to interpret the step incorrectly and so there is a higher chance of them completing the step without any errors.

5.0 Conclusions

1. While further investigation with larger samples is needed, the current results tentatively suggest that pictogram based instructions offer a number of performance benefits over static images for the purpose of delivering assembly work instructions in terms of lower overall build times, fewer build errors and lower times required to correct errors.

2. Importantly, the spread in build times reduced noticeably with build number for both media types, demonstrating that all participants were learning, in particular those who had long initial build times.

3. There was no discernible difference between the number of media references made by the pictogram and image groups.

References

[1] Anon. The Smarter Supply Chain of The Future: Global Chief Supply Chain Officer Study. IBM, Document Number GBE03163USEN. http://www-01.ibm.com/common/ssi/cgi-, Downloaded July 2015. bin/ssialias?infotype=PM&subtype=XB&htmlfid=GBE03163USEN

[2] Butterfield J., Watson G., Curran R., and Craig C. "Do dynamic work instructions provide an advantage over static instructions in a small scale assembly task?" Learning and Instruction 20, 2010: 84 - 93. doi:10.1016/j.learninstruc.2009.05.001.

[3] McEwan, W. and Butterfield, J. 2011. The use of process simulation methods in support of organisational learning in availability contracting. Journal of Aerospace Operations, 1, pp. 41-53.

[4] Butterfield, J., McClean, A., Jin, Y., Curran, R., Burke, R., Welch, B. and Devenny, C. 2010. Use of digital manufacturing to improve management learning in aerospace assembly. AIAA Journal of Aircraft, 47 (1), pp. 315-322.

[5] Dorrian M., Butterfield J., Stewart K., Whyatt C., Cole J., Brown C., Welch B., Burke R., International Manufacturing Conference (IMC31), Cork Institute of Technology, 4 – 5 Sept 2014, Cork, Ireland.
[6] Hasler, B.S., Kersten, B. and Sweller, J. 2007. Learner control, cognitive load and instructional animation. Applied Cognitive Psychology, 21 (6), pp. 713-729.
[7] Paas, F., Tuovinen, J.E., Tabbers, H. and Van Gerven, P.W.M. 2003. Cognitive load measurement as a means to advance cognitive load theory. Educational Psychologist, 38 (1), pp. 63-71.